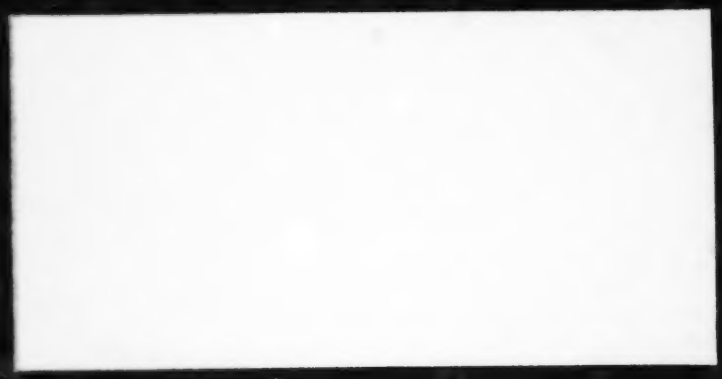
Environment Canada Environnement Canada
0050390D DEST PVM EXCH COPY 03
TP 360 E5713
VOL ISS 256
ENFOR PROJECT P



Contractor's Final Report [1/]
DSS Contract 43SS.KH415-3-0087

ENFOR Project P-256

Determination of Available Heat of Combustion Data for Canadian Woody Species

by

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February 1984

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ABSTRACT

A literature review was conducted to obtain reliable, experimentally determined calorific data for the various components of Canadian tree species. Information was obtained for 48 tree species native to Canada and is presented in tabular form. For indigenous species, the overall mean calorific value was found to be 21.18 MJ/kg for softwood materials (i.e. stem wood, stem bark, foliage, etc.) compared to 19.35 MJ/kg for hardwoods. Variation between reported values for a component of a particular species was found to be generally less than 5 percent but, in some instances, exceeded 10 percent. Calorific data are also presented for hybrid poplar and for several foreign species commonly planted in Canada. It is recommended that experimental research be conducted to form a complete calorific value checklist which could be used to supplement Canadian biomass inventory data.

1. INTRODUCTION

The calorific value of a material is the amount of heat released when the substance is completely combusted under controlled conditions. Analogous terms to calorific value are heat of combustion, gross heat of combustion, heating value, gross heating value, higher heating value, fuel value, and caloric value.

The calorific value of wood is commonly assumed to be about 19.76 MJ/ovendry kg. In general, due to differences in chemical composition, the calorific values of softwoods, on a weight basis, are higher than those of hardwoods. However, when compared on a volumetric basis such as a cunit, hardwoods, due to their higher densities, usually offer greater heating potentials than softwoods.

Calorific data have been traditionally determined on clear samples removed from the bole section of the tree. Such samples may not be representative of the forest material mixes which are likely to be used as fuel materials in the future. In current ENFOR Production studies, ovendry mass of the tree is typically broken down and calculated according to component (i.e. stem, branch, foliage, etc.). In most, if not all cases, calorific values have not been presented for the various components and it has been commonly supposed that the average value of 19.76 MJ/kg is suitable. Due to their increasing importance as renewable fuels, there is a necessity to accurately ascertain the calorific values of the different Canadian tree species and their components.

The purpose of this project is:

(1) To review the literature and prepare a checklist of reliable calorific data for Canadian tree species, broken down by components, which could be used to supplement the ENFOR biomass inventory data, and

(2) To provide cost estimates for determining calorific values of important tree species for which no data are currently available.

2. METHODS

Information on the calorific values of forest materials was gathered using the following methods:

(1) Conducting an on-line retrospective literature search.

(2) Conducting a manual literature search through relevant journals and abstracts.

(3) Contacting, by letter, institutions in Canada and the United States which may have conducted research in calorimetry or wood energy.

As shown in the Bibliography, approximately 80 articles pertaining to calorific values of forest materials were obtained. However, many of these articles presented non-experimental calorific data or data for trees not grown in Canada. Literature which contained calorific data of uncertain derivation was not used for the final species checklist.

The most common technique currently used for determination of calorific value follows the methods of ASTM, in which ground samples are combusted in an adiabatic oxygen bomb calorimeter. The measured calorific value is corrected for the heat of combustion of the fuse wire and the heats of formation of nitric and sulphuric acids. The corrected calorific value is usually expressed on a basis of the original, ovendry sample mass. Data which were obtained using the ASTM or an equivalent method were included in the species checklist.

In total, approximately 35 of the retrieved articles contained information which was used in the species checklist. All calorific values for the checklist were converted to SI units (Megajoules/kilogram [MJ/kg]) using the following conversion factors:

1 British thermal unit = 1055.07 Joules

1 Calorie = 4.1868 Joules

1 Kilogram = 2.2045 Pounds

3. RESULTS

3.1 Results of Literature Search

Tables 1 to 54 show the final selection of calorific values which were obtained from the information search. The values are presented under the following main headings:

(1) Trees Native to Canada

(2) Hybrid Poplar

(3) Foreign Trees Commonly Grown in Canada

The order of species presentation for heading (1) follows the order of species in Native Trees of Canada (Hosie 1969).

The following points should be considered when utilizing the species list:

(1) In most cases, the calorific values were corrected for the heats of formation of sulphuric and nitric acids. In some cases, no compensations were made for the formation of these acids. However, since nitrogen and especially sulphur levels of forest materials are low, the variations due to lack of corrections were considered to be negligible.

(2) In all cases, the gross calorific values are presented in contrast to net calorific values, which are corrected for hydrogen content and water formation.

(3) In the majority of instances, calorific values are expressed on the initial total ovendry mass basis. In some cases, the values are expressed on an ash-free or air-dry basis. Such differences are noted directly in the tables.

(4) The tree component (i.e. stem, branch, etc.) from where the sample was obtained was usually specified in each article. Where unspecified, the sample was assumed to originate from the main stem.

(5) Foliage calorific data were assumed to be determined from material collected while fresh, unless otherwise specified in the article. Actual methods used for drying foliage prior to calorific testing were not detailed in most articles. Foliage calorific values may therefore show some variation, depending upon the specific drying conditions used. When dead foliage was collected and tested, a note is included in the table.

(6) When the actual geographic source of sampling was not mentioned in the article, the specimen source was usually assumed to be the same as the location in which the calorific testing was conducted.

(7) Most oxygen bomb testing was conducted on materials ground to pass a 250 µm sieve. In some cases, larger particle sizes were used. Samples were tested either in loose or in pellet form. These testing differences are not noted in the test since they are not expected to contribute to a large variation in calorific value.

(8) The term composite utilized in the tables refers to sample mixtures of different components (i.e. wood and bark mixture).

(9) All table headings include both the common and scientific names for the species. However, in some articles, only common names were given. In these instances, appropriate scientific names were selected from Native Trees of Canada (Hosie 1969).

3.2 Calorific Values of Trees Native to Canada

Table 1. EASTERN WHITE PINE (*Pinus strobus* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	21.01	New Hampshire	--	Musselman and Hocker 1981
Stem bark	22.44	U.S.	--	Harder and Einspahr 1978
Branch wood	21.36	New Hampshire	--	Musselman and Hocker 1981
Branch; composite wood and bark	22.51	New Hampshire	--	Musselman and Hocker 1981
Foliage	21.88	New Hampshire	--	Musselman and Hocker 1981

Table 2. WESTERN WHITE PINE (*Pinus monticola* Dougl.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Branch bark	21.76	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Twigs	22.07	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
Foliage	21.03	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	21.76	Northwestern U.S.	Dead foliage; expressed on ash-free basis	Susott 1982

Table 3. PONDEROSA PINE (*Pinus ponderosa* Laws.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.82	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	20.97	Northwestern U.S.	Material from heartwood lumber; expressed on ash-free basis	Susott 1982
Stem bark	22.01	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	22.37	U.S.	--	Harder and Einspahr 1976
Branch bark	21.99	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Twigs	23.32	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
Foliage	21.81	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	22.91	Northwestern U.S.	Dead foliage; expressed on ash-free basis	Susott 1982
	22.16	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	21.54	U.S.	--	Susott et al. 1975

Table 4. RED PINE (*Pinus resinosa* Ait.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	21.10	U.S.	--	Harder and Einspahr 1976
Foliage	21.84	Ontario	Calorific value determined by peroxide bomb calorimeter	Van Wagner 1972

Table 5. JACK PINE (*Pinus banksiana* Lamb.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.15	Wisconsin	Material from 10-year-old tree	Zavitkovski 1979
	19.40	Ontario	Material from sawdust	Ross 1983
Stem bark	21.30	Ontario	--	Ross 1983
	21.84	Wisconsin	Material from 10-year-old tree	Zavitkovski 1979
	21.85	U.S.	--	Harder and Einspahr 1976
	20.21	Ontario	Material from slash; calorific value determined by peroxide bomb calorimeter	Van Wagner 1972
	20.38	Wisconsin	Expressed at a moisture content of 6.6%, dry basis	Chang and Mitchell 1955
	20.77	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955
Branch wood	19.20	Ontario	Material from slash; calorific value determined by peroxide bomb calorimeter	Van Wagner 1972
Branch; composite wood and bark	21.95	Wisconsin	Material from 10-year-old tree; presumably composite sample	Zavitkovski 1979

Table 5. JACK PINE (*Pinus banksiana* Lamb.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Twigs	21.67	Minnesota	--	Hough 1969
Foliage	21.63	Wisconsin	Material from 10-year-old tree	Zavitkovski 1979
	21.71	Ontario	Calorific value determined by peroxide bomb calorimeter	Van Wagner 1972
	21.36	Minnesota	--	Hough 1969
Roots	21.00	Wisconsin	Material from 10-year-old tree	Zavitkovski 1979

Table 6. LODGEPOLE PINE (*Pinus contorta* Dougl.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	23.70	Washington	Expressed at a moisture content of 5.6%, dry basis	Chang and Mitchell 1955
	21.82	U.S.	--	Harder and Einspahr 1976
Branch bark	22.34	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Branch; composite wood and bark	20.64	Northwestern U.S.	Material sampled from forest floor	Ryan and Pickford 1978
Twigs	21.80	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	20.56	Northwestern U.S.	Material sampled from forest floor	Ryan and Pickford 1978
Foliage	22.14	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	21.78	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	21.03	Alberta	Foliage age ranged from 6 to 13 months; average value for samples dried by 2 different methods	Boag and Kiceniuk 1968

Table 7. TAMARACK (*Larix laricina* [Du Roi] K. Koch)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	20.96	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955
Foliage	19.41	Pennsylvania	--	Hough 1969

Table 6. WESTERN LARCH (*Larix occidentalis* Nutt.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.83	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	20.22	Northwestern U.S.	Material from lumber; expressed on ash-free basis	Susott 1982
	19.47	Northwestern U.S.	Material from heartwood	Susott et al. 1976
Stem bark	23.82	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	20.53	U.S.	--	Harder and Einspahr 1976
	19.08	Montana	Expressed at a moisture content of 6.7%, dry basis	Chang and Mitchell 1955
Branch bark	21.31	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Branch; composite wood and bark	21.17	Northwestern U.S.	Material sampled from forest floor	Ryan and Pickford 1978
Twigs	21.51	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	21.21	Northwestern U.S.	Material sampled from forest floor	Ryan and Pickford 1978
	20.24	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979

Table 9. WHITE SPRUCE (*Picea glauca* [Moench] Voss)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.78	Eastern Canada	Average of tests conducted on various particle sizes; material obtained from kiln-dried lumber	Kryla 1973b
Stem bark	20.73	U.S.	--	Harder and Einspahr 1976
	19.84	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955
Twigs	21.23	Minnesota	--	Hough 1969
Foliage	19.68	Minnesota	--	Hough 1969

Table 10. ENGELMANN SPRUCE (*Picea engelmannii* Parry)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	20.54	U.S.	--	Harder and Einspahr 1976
	19.44	Idaho	Expressed at a moisture content of 5.5%, dry basis	Chang and Mitchell 1955
Branch bark	22.37	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Twigs	21.11	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
Foliage	20.48	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979

Table 11. RED SPRUCE (*Picea rubens* Sarg.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	20.07	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955

Table 12. BLACK SPRUCE (*Picea mariana* [Mill.] B.S.P.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	21.27	U.S.	--	Harder and Einspahr 1978
	19.18	Wisconsin	Expressed at a moisture content of 6.5%, dry basis	Chang and Mitchell 1955
	20.03	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955
Twigs	21.46	Minnesota	--	Hough 1969
Foliage	20.62	Minnesota	--	Hough 1969

Table 13. EASTERN HEMLOCK (*Tsuga canadensis* [L.] Carr.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	22.14	U.S.	--	Harder and Einspahr 1978
	20.47	Wisconsin	Expressed at a moisture content of 6.2%, dry basis	Chang and Mitchell 1955
	20.68	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955

Table 14. WESTERN HEMLOCK (*Tsuga heterophylla* [Raf.] Sarg.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	21.62	U.S.	--	Harder and Einspahr 1976
Stem; composite wood and bark	20.13	England	--	Ovington and Heitkamp 1960
Branch bark	23.13	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Branch; composite wood, bark, and foliage	20.62	England	--	Ovington and Heitkamp 1960
Twigs	20.76	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
Foliage	22.08	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	20.77	England	--	Ovington and Heitkamp 1960

Table 15. DOUGLAS-FIR (*Pseudotsuga menziesii* [Mirb.] Franco)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.25	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	20.09	Northwestern U.S.	Material from lumber; expressed on ash-free basis	Susott 1982
Stem bark	23.96	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	23.17	U.S.	--	Harder and Einspahr 1976
Branch bark	25.23	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Branch; composite wood and bark	20.30	Northwestern U.S.	Material sampled from forest floor	Ryan and Pickford 1978
Young stem	22.38	Northwestern U.S.	Presumably composite wood and bark; unspecified age: expressed on ash-free basis	Susott 1982
Twigs	21.20	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	20.51	Northwestern U.S.	Material sampled from forest floor	Ryan and Pickford 1978
Foliage	22.30	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	21.55	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
Decayed wood	23.05	Northwestern U.S.	Unspecified decay; expressed on ash-free basis	Susott 1982

Table 16. BALSAM FIR (*Abies balsamea* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.04	Minnesota	--	Barnes and Sinclair 1983
Stem bark	21.72	U.S.	--	Harder and Einsphahr 1976
	20.61	Wisconsin	Expressed at a moisture content of 6.5%, dry basis	Chang and Mitchell 1955
Twigs	21.10	Minnesota	--	Hough 1969
Foliage	21.38	New Brunswick	Average for fertilized and non-fertilized materials; expressed on ash-free basis	Shaw et al. 1978
	20.93	New Brunswick	Current-year foliage average estimated from graph; expressed on ash-free basis	Shaw and Little 1977
	23.00	Ontario	Calorific value determined by peroxide bomb calorimeter	Van Wagner 1972
	21.19	Minnesota	--	Hough 1969
Stem wood; spruce budworm-killed	19.90 - 20.00	Minnesota	Tree death from 6 to 22 months	Barnes and Sinclair 1983

Table 17. GRAND FIR (*Abies grandis* [Dougl.] Lindl.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.25	Northwestern U.S.	Expressed on ash-free basis	Susott 1982
	19.58	England	May be composite wood and bark	Ovington and Heitkamp 1960
Branch bark	22.43	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Branch; composite wood and bark	20.14	Northwestern U.S.	Material sampled from forest floor	Ryan and Pickford 1978
Branch; composite wood, bark, and foliage	20.39	England	--	Ovington and Heitkamp 1960
Twigs	20.69	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	20.32	Northwestern U.S.	Material sampled from forest floor	Ryan and Pickford 1978
Foliage	22.09	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	20.80	England	--	Ovington and Heitkamp 1960

Table 18. WESTERN RED CEDAR (*Thuja plicata* Donn)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.65	England	May be composite wood and bark	Ovington and Heitkamp 1960
Branch bark	20.16	Northwestern U.S.	Material obtained from slash; may include stem bark	Kelsey et al. 1979
Branch; composite wood, bark, and foliage	20.54	England	--	Ovington and Heitkamp 1960
Twigs	20.65	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
Foliage	22.40	Northwestern U.S.	Material obtained from slash	Kelsey et al. 1979
	20.99	England	--	Ovington and Heitkamp 1960

Table 19. WILLOW (*Salix* spp.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	16.67	Illinois	Black willow (*Salix nigra* Marsh.); expressed at a moisture content of 6.7%, dry basis	Chang and Mitchell 1955
	18.93	U.S.	Black willow	Harder and Einspahr 1978
Stem; composite wood and bark	19.66	Ontario	Material from 6-year-old tree	Kryla 1983a
	16.43	Kansas	Sandbar willow (*Salix exigua* Nutt.); material from 2-year-old tree	Geyer 1981
Branch; composite wood and bark	19.89	Ontario	Material from 6-year-old tree	Kryla 1983a
	18.65	Kansas	Sandbar willow; material from 2-year-old tree; includes branches and tops	Geyer 1981

Table 20. TREMBLING ASPEN (*Populus tremuloides* Michx.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.71	New Hampshire	--	Musselman and Hocker 1981
	19.35	Eastern Canada	Average of tests conducted on various particle sizes; material obtained from kiln-dried lumber	Kryla 1983b
Stem bark	20.26	U.S.	--	Harder and Einspahr 1976
	19.62	Wisconsin	Expressed at moisture content of 5.5%, dry basis	Chang and Mitchell 1955
Stem; composite wood and bark	19.22	Alberta	--	Peterson et al. 1970
Branch wood	20.41	New Hampshire	--	Musselman and Hocker 1981
Branch; composite wood and bark	20.83	New Hampshire	--	Musselman and Hocker 1981
	19.54	Alberta	--	Peterson et al. 1970
Twig wood	19.05	Ontario	Expressed on ash-free basis	James and Smith 1978
Twig bark	21.10	Ontario	Expressed on ash-free basis	James and Smith 1978
Twig; composite wood and bark	20.36	Minnesota	--	Hough 1969
Foliage	22.65	Northwestern U.S.	Expressed on ash-free basis	Susott 1982

Table 20. TREMBLING ASPEN (*Populus tremuloides* Michx.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Foliage (cont'd)	22.44	New Hampshire	--	Musselman and Hocker 1981
	21.65	Ontario	Expressed on ash-free basis	James and Smith 1978
	21.08	U.S.	--	Susott et al. 1975
	19.76	Alberta	--	Peterson et al. 1970
	21.16	Minnesota	--	Hough 1969
Wood decayed by brown-rot	18.32	U.S.	Average value for various degrees of decomposition (*Populus* spp.); undecayed control = 12.20 MJ/kg	Blankenhorn 1980
Wood decayed by white-rot	18.98	U.S.	Average value for various degrees of decomposition (*Populus* spp.); undecayed control = 19.20 MJ/kg	Blankenhorn 1980
Twig: dead material	18.74	Ontario	Calorific value determined by peroxide bomb calorimeter	Van Wagner 1972

Table 21. EASTERN COTTONWOOD (*Populus deltoides* Bartr.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	19.59	U.S.	--	Harder and Einspahr 1976
Stem; composite wood and bark	18.22	Kansas	Material from 2-year-old tree	Geyer 1981
Branch; composite wood and bark	19.01	Kansas	Material from 2-year-old tree; includes branches and tops	Geyer 1981

Table 22. HICKORY (*Carya* spp.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.33	Alabama	Material from bottomland site	Gower et al. 1983
	19.03	U.S.	Material from southern pine site	Koch 1983
Stem bark	17.53	Alabama	Material from bottomland site	Gower et al. 1983
	17.65	U.S.	Material from southern pine site	Koch 1983
	19.59	U.S.	Shagbark hickory (*Carya ovata* [Mill.]) K. Koch)	Harder and Einspahr 1978
Branch wood	18.89	Alabama	Material from bottomland site	Gower et al. 1983
	18.45	U.S.	Material from southern pine site	Koch 1983
Branch bark	17.60	Alabama	Material from bottomland site	Gower et al. 1983
	16.88	U.S.	Material from southern pine site	Koch 1983
Foliage	19.16	Alabama	Material from bottomland site	Gower et al. 1983

Table 22. HICKORY (*Carya* spp.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Root wood	19.23	U.S.	Material from southern pine site	Koch 1983
Root bark	17.21	U.S.	Material from southern pine site	Koch 1983

Table 23. YELLOW BIRCH (*Betula alleghaniensis* Britton)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.77	New Hampshire	--	Musselman and Hocker 1981
Stem bark	21.11	Wisconsin	Expressed at a moisture content of 5.2%, dry basis	Chang and Mitchell 1955
	21.40	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955
Branch wood	20.74	New Hampshire	--	Musselman and Hocker 1981
Branch; composite wood and bark	20.94	New Hampshire	--	Musselman and Hocker 1981
Foliage	19.78	New Hampshire	--	Musselman and Hocker 1981

Table 24. WHITE BIRCH (*Betula papyrifera* Marsh.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	18.82	Ontario	Expressed on ash-free basis; value is average of samples from 3 different sites; calorific values estimated from graph	Smith and Tumey 1982
	20.81	New Hampshire	--	Musselman and Hocker 1981
Stem bark	24.03	U.S.	--	Harder and Einspahr 1976
	21.94	Wisconsin	Expressed at a moisture content of 4.8%, dry basis	Chang and Mitchell 1955
	23.98	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955
Branch wood	21.11	New Hampshire	--	Musselman and Hocker 1981
Branch; composite wood and bark	21.50	New Hampshire	--	Musselman and Hocker 1981
Foliage	21.93	New Hampshire	--	Musselman and Hocker 1981

Table 25. RED ALDER (*Alnus rubra* Bong.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	20.38	U.S.	--	Harder and Einspahr 1978
	18.48	Oregon	Expressed at a moisture content of 5.8%, dry basis	Chang and Mitchell 1955

Table 26. SPECKLED ALDER (*Alnus rugosa* [Du Roi] Spreng.(*Alnus incana* [L.] Moench))

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.30	England	May be composite wood and bark	Ovington and Heitkamp 1960
Stem; composite wood and bark	19.87	Ontario	Material from 10-year-old tree	Kryla 1983a
Branch; composite wood and bark	20.23	Ontario	Material from 10-year-old tree	Kryla 1983a
Branch; composite wood, bark, and foliage	20.69	England	--	Ovington and Heitkamp 1960
Foliage	19.98	England	--	Ovington and Heitkamp 1960

Table 27. AMERICAN BEECH (*Fagus grandifolia* Ehrh.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	18.59	U.S.	--	Harder and Einspahr 1978
	17.77	Eastern Canada	Experimentally determined; testing procedures not detailed	Millikin 1955

Table 28. WHITE OAK (*Quercus alba* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	17.85	U.S.	Material from southern pine site	Koch 1983
Stem bark	17.05	U.S.	Material from southern pine site	Koch 1983
	20.31	U.S.	Outer bark	Sandala et al. 1981
	15.69	U.S.	Inner bark	Sandala et al. 1981
	17.53	U.S.	--	Harder and Einspahr 1976
	16.27	Illinois	Expressed at a moisture content of 6.5%, dry basis	Chang and Mitchell 1955
Branch wood	17.46	U.S.	Material from southern pine site	Koch 1983
Branch bark	17.62	U.S.	Material from southern pine site	Koch 1983
Root wood	18.82	U.S.	Material from southern pine site	Koch 1983
Root bark	16.91	U.S.	Material from southern pine site	Koch 1983

Table 29. RED OAK (*Quercus rubra* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	18.12	U.S.	Material from southern pine site	Koch 1983
	20.13	New Hampshire	--	Musselman and Hocker 1981
	19.95	U.S.	Material obtained from chips; tests conducted on extractive-free material	Murphey and Masters 1978
Stem bark	18.33	U.S.	Material from southern pine site	Koch 1983
	25.20	U.S.	Outer bark	Sandala et al. 1981
	19.24	U.S.	Inner bark	Sandala et al. 1981
	20.69	U.S.	--	Harder and Einspahr 1976
	18.68	Illinois and Wisconsin	Expressed at a moisture content of 4.4%, dry basis	Chang and Mitchell 1955
Branch wood	18.09	U.S.	Material from southern pine site	Koch 1983
	20.13	New Hampshire	--	Musselman and Hocker 1981
Branch bark	18.44	U.S.	Material from southern pine site	Koch 1983
Branch; composite wood and bark	20.46	New Hampshire	--	Musselman and Hocker 1981

Table 29. RED OAK (*Quercus rubra* L.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Foliage	20.80	New Hampshire	--	Musselman and Hocker 1981
Root wood	18.54	U.S.	Material from southern pine site	Koch 1983
Root bark	17.87	U.S.	Material from southern pine site	Koch 1983

Table 30. BLACK OAK (*Quercus velutina* Lam.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	17.66	U.S.	Material from southern pine site	Koch 1983
Stem bark	17.78	U.S.	Material from southern pine site	Koch 1983
	19.40	U.S.	--	Harder and Einspahr 1978
Branch wood	17.89	U.S.	Material from southern pine site	Koch 1983
Branch bark	18.25	U.S.	Material from southern pine site	Koch 1983
Foliage	21.27	U.S.	Expressed on an ash-free basis; dead foliage	Susott 1982
Root wood	19.02	U.S.	Material from southern pine site	Koch 1983
Root bark	18.30	U.S.	Material from southern pine site	Koch 1983

Table 31. PIN OAK (*Quercus palustris* Muenchh.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	20.66	U.S.	--	Harder and Einspahr 1978

Table 32. WHITE ELM (*Ulmus americana* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	18.07	U.S.	Material from southern pine site	Koch 1983
Stem bark	15.91	U.S.	Material from southern pine site	Koch 1983
	16.10	Illinois and Mississippi	Expressed at a moisture content of 6.7%, dry basis	Chang and Mitchell 1955
Branch wood	18.28	U.S.	Material from southern pine site	Koch 1983
Branch bark	16.06	U.S.	Material from southern pine site	Koch 1983
Root wood	19.17	U.S.	Material from southern pine site	Koch 1983
Root bark	16.68	U.S.	Material from southern pine site	Koch 1983

Table 33. HACKBERRY (*Celtis* spp.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	18.33	U.S.	Material from southern pine site	Koch 1983
Stem bark	16.62	U.S.	Material from southern pine site	Koch 1983
Branch wood	18.30	U.S.	Material from southern pine site	Koch 1983
Branch bark	16.61	U.S.	Material from southern pine site	Koch 1983
Root wood	21.02	U.S.	Material from southern pine site	Koch 1983
Root bark	16.28	U.S.	Material from southern pine site	Koch 1983

Table 34. TULIP-TREE (*Liriodendron tulipifera* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	18.08	U.S.	Material from southern pine site	Koch 1983
	20.18	Georgia	Material from trees with average age of 14 years	Neenan and Steinbeck 1979
Stem bark	17.90	U.S.	Material from southern pine site	Koch 1983
	19.39	Georgia	Material from trees with average age of 14 years	Neenan and Steinbeck 1979
	20.83	U.S.	--	Harder and Einspahr 1978
Branch wood	18.17	U.S.	Material from southern pine site	Koch 1983
Branch bark	17.83	U.S.	Material from southern pine site	Koch 1983
Branch; composite wood and bark	20.10	Georgia	Material from trees with average age of 14 years	Neenan and Steinbeck 1979
Twigs	20.02	Georgia	Material from trees with average age of 14 years	Neenan and Steinbeck 1979
Foliage	21.21	Georgia	Material from trees with average age of 14 years	Neenan and Steinbeck 1979

Table 34. TULIP-TREE (*Liriodendron tulipifera* L.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Root wood	20.32	U.S.	Material from southern pine site	Koch 1983
Root bark	18.09	U.S.	Material from southern pine site	Koch 1983

Table 35. SYCAMORE (*Platanus occidentalis* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.91	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979
Stem bark	20.01	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979
	18.56	U.S.	--	Harder and Einspahr 1978
	17.22	Illinois	Expressed at a moisture content of 6.4%, dry basis	Chang and Mitchell 1955
Stem; composite wood and bark	19.36	Kansas	Material from 2-year-old tree	Geyer 1981
Branch; composite wood and bark	18.85	Kansas	Material from 2-year-old tree; includes branches and tops	Geyer 1981
	20.33	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979
Twigs	20.40	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979
Foliage	21.65	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979

Table 36. AMERICAN MOUNTAIN-ASH (*Sorbus americana* Marsh.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem; composite wood and bark	19.63	Ontario	Material from 12-year-old tree	Kryla 1983a
Branch; composite wood and bark	19.60	Ontario	Material from 12-year-old tree	Kryla 1983a

Table 37. BLACK CHERRY (*Prunus serotina* Ehrh.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	18.66	Ontario	Expressed on ash-free basis; value is average of samples from 3 different sites; calorific values estimated from graph	Smith and Tumey 1982
	19.95	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
Stem bark	25.91	U.S.	Outer bark	Sandala et al. 1981
	22.12	U.S.	Inner bark	Sandala et al. 1981
	20.72	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
Branch; composite wood and bark	20.27	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
Twigs	20.37	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
Foliage	21.91	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979

Table 38. STAGHORN SUMAC (*Rhus typhina* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem; composite wood and bark	19.69	Ontario	Material from 6-year-old tree	Kryla 1983a
Branch; composite wood and bark	20.05	Ontario	Material from 6-year-old tree	Kryla 1983a

Table 39. SUGAR MAPLE (*Acer saccharum* Marsh.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.75	Vermont-Maine	--	Bennink 1983
	18.96	Ontario	Expressed on ash-free basis; value is average of samples from 3 different sites; calorific values estimated from graph	Smith and Tumey 1982
	20.41	New Hampshire	--	Musselman and Hocker 1981
Stem bark	19.60	U.S.	--	Harder and Einspahr 1976
	16.98	Illinois	Expressed at a moisture content of 6.0%, dry basis	Chang and Mitchell 1955
Branch wood	20.62	New Hampshire	--	Musselman and Hocker 1981
Branch; composite wood and bark	20.40	New Hampshire	--	Musselman and Hocker 1981
Foliage	20.98	New Hampshire	--	Musselman and Hocker 1981
Sprout wood	19.28	U.S.	Material from 3-year-old tree	Lai et al. 1979
Sprout bark	19.13	U.S.	Material from 3-year-old tree	Lai et al. 1979

Table 39. SUGAR MAPLE (*Acer saccharum* Marsh.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Seedling wood	19.32	U.S.	Material from 6-year-old tree	Lai et al. 1979
Seedling bark	18.59	U.S.	Material from 6-year-old tree	Lai et al. 1979

Table 40. SILVER MAPLE (*Acer saccharinum* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	19.45	U.S.	--	Harder and Einspahr 1976
Stem; composite wood and bark	18.62	Kansas	Material from 2-year-old tree	Geyer 1981
Branch; composite wood and bark	18.77	Kansas	Material from 2-year-old tree	Geyer 1981

Table 41. RED MAPLE (*Acer rubrum* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.62	South Carolina	Material from bottomland site	Gower et al. 1983
	18.25	U.S.	Material from southern pine site	Koch 1983
	20.32	New Hampsnire	--	Musselman and Hocker 1981
	20.13	Georgia	Material from trees with average age of 13 years	Neenan and Steinbeck 1979
Stem bark	17.79	South Carolina	Material from bottomland site	Gower et al. 1983
	17.67	U.S.	Material from southern pine site	Koch 1983
	19.08	Georgia	Material from trees with average age of 13 years	Neenan and Steinbeck 1979
	19.29	U.S.	--	Harder and Einspahr 1978
Branch wood	19.41	South Carolina	Material from bottomland site	Gower et al. 1979
	18.21	U.S.	Material from southern pine site	Koch 1983
	20.31	New Hampshire	--	Musselman and Hocker 1981
Branch bark	16.61	South Carolina	Material from bottomland site	Gower et al. 1983

Table 41. RED MAPLE (*Acer rubrum* L.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Branch bark (cont'd)	17.18	U.S.	Material from southern pine site	Koch 1983
Branch; composite wood and bark	20.16	New Hampshire	--	Musselman and Hocker 1981
	19.93	Georgia	Material from trees with average age of 13 years	Neenan and Steinbeck 1979
Twigs	19.97	Georgia	Material from trees with average age of 13 years	Neenan and Steinbeck 1979
Foliage	20.39	South Carolina	Material from bottomland site	Gower et al. 1983
	21.21	New Hampshire	--	Musselman and Hocker 1981
	20.63	Georgia	Material from trees with average age of 13 years	Neenan and Steinbeck 1979
Root wood	19.56	U.S.	Material from southern pine site	Koch 1983
Root bark	17.25	U.S.	Material from southern pine site	Koch 1983

Table 42. MOUNTAIN MAPLE (*Acer spicatum* Lam.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem; composite wood and bark	19.75	Ontario	Material from 11-year-old tree	Kryla 1983a
Branch; composite wood and bark	20.02	Ontario	Material from 11-year-old tree	Kryla 1983a

Table 43. STRIPED MAPLE (*Acer pensylvanicum* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Lower-stem; composite wood and bark	19.20	Ontario	Material from 12-year-old tree	Kryla 1983a
Mid-stem; composite wood and bark	19.06	Ontario	Material from 12-year-old tree	Kryla 1983a
Branch; composite wood and bark	19.56	Ontario	Material from 12-year-old tree	Kryla 1983a

Table 44. MANITOBA MAPLE (*Acer negundo* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.49	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979
Stem bark	18.09	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979
Stem; composite wood and bark	19.05	Kansas	Material from 2-year-old tree	Geyer 1981
Branch; composite wood and bark	18.56	Kansas	Material from 2-year-old tree; includes branches and tops	Geyer 1981
	20.44	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979
Twigs	20.26	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979
Foliage	21.05	Georgia	Material from trees with average age of 11 years	Neenan and Steinbeck 1979

Table 45. bLACK GUM (*Nyssa sylvatica* Marsh.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.69	Mississippi	Material from swamp site	Gower et al. 1983
	18.30	U.S.	Material from southern pine site	Koch 1983
Stem bark	19.53	Mississippi	Material from swamp site	Gower et al. 1983
	18.12	U.S.	Material from southern pine site	Koch 1983
	18.85	U.S.	--	Harder and Einspahr 1978
	18.46	Illinois	Expressed at a moisture content of 6.0%, dry basis	Chang and Mitchell 1955
Branch wood	19.92	Mississippi	Material from swamp site	Gower et al. 1983
	18.18	U.S.	Material from southern pine site	Koch 1983
Branch bark	20.13	Mississippi	Material from swamp site	Gower et al. 1983
	19.02	U.S.	Material from southern pine site	Koch 1983
Foliage	20.91	Mississippi	Material from swamp site	Gower et al. 1983

Table 45. BLACK GUM (*Nyssa sylvatica* Marsh.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Root wood	16.87	U.S.	Material from southern pine site	Koch 1983
Root bark	18.16	U.S.	Material from southern pine site	Koch 1983

Table 46. WHITE ASH (*Fraxinus americana* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	18.69	U.S.	Material from southern pine site	Koch 1983
	19.53	New Hampshire	--	Musselman and Hocker 1981
Stem bark	17.90	U.S.	Material from southern pine site	Koch 1983
	19.66	U.S.	--	Harder and Einspahr 1978
Branch wood	18.64	U.S.	Material from southern pine site	Koch 1983
Branch bark	18.18	U.S.	Material from southern pine site	Koch 1983
Branch; composite wood and bark	20.13	New Hampshire	--	Musselman and Hocker 1981
Foliage	20.09	New Hampshire	--	Musselman and Hocker 1981
Root wood	19.19	U.S.	Material from southern pine site	Koch 1983
Root bark	18.06	U.S.	Material from southern pine site	Koch 1983
Sprout wood	19.18	U.S.	Material from 3-year-old tree	Lai et al. 1979
Sprout bark	18.57	U.S.	Material from 3-year-old tree	Lai et al. 1979

Table 46. WHITE ASH (*Fraxinus americana* L.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Seedling wood	19.22	U.S.	Material from 6-year-old tree	Lai et al. 1979
Seedling bark	19.07	U.S.	Material from 6-year-old tree	Lai et al. 1979

Table 47. RED ASH (*Fraxinus pennsylvanica* Marsh.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.44	South Carolina	Material from bottomland site	Gower et al. 1983
	17.90	U.S.	Material from southern pine site	Koch 1983
	19.96	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
Stem bark	19.15	South Carolina	Material from bottomland site	Gower et al. 1983
	17.38	U.S.	Material from southern pine site	Koch 1983
	19.33	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
	19.46	U.S.	--	Harder and Einspahr 1978
Branch wood	19.65	South Carolina	Material from bottomland site	Gower et al. 1983
	17.97	U.S.	Material from southern pine site	Koch 1983
Branch bark	19.60	South Carolina	Material from bottomland site	Gower et al. 1983
	17.69	U.S.	Material from southern pine site	Koch 1983

Table 47. RED ASH (*Fraxinus pennsylvanica* Marsh.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Branch; composite wood and bark	20.34	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
Twigs	20.17	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
Foliage	19.59	South Carolina	Material from bottomland site	Gower et al. 1983
	21.43	Georgia	Material from trees with average age of 12 years	Neenan and Steinbeck 1979
Root wood	19.35	U.S.	Material from southern pine site	Koch 1983
Root bark	17.25	U.S.	Material from southern pine site	Koch 1983

Table 48. NANNYBERRY (*Viburnum lentago* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem and branch; composite wood and bark	20.37	Ontario	Material from 6-year-old tree	Kryla 1983a

3.3 Calorific Values of Hybrid Poplar

Table 49. HYBRID POPLAR (*Populus* spp.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.55	Czechoslovakia	*Populus canadensis* cv. *marilandica*	Necesany and Oberlanderova 1980
	19.71	Czechoslovakia	Reaction wood; *Populus canadensis* cv. *marilandica*	Necesany and Oberlanderova 1980
	19.38	Wisconsin	Lower stem; average value of 4 clones black poplar parentage; 4-year-old tree	Strong 1980
	19.31	Wisconsin	Lower stem; average value of 4 clones balsam poplar parentage; 4-year-old tree	Strong 1980
	19.72	Wisconsin	Upper stem; average value of 4 clones black poplar parentage; 4-year-old tree	Strong 1980
	19.65	Wisconsin	Upper stem; average value of 4 clones balsam poplar parentage; 4-year-old tree	Strong 1980
	19.31	Wisconsin	*Populus tristis* x *P. balsamifera*; 10-year-old tree	Zavitkovski 1979
	19.19	Pennsylvania	*Populus maximowiczii* x *P. trichocarpa*, Clone NE-388; average value for 5 different growth spacings	Holt and Murphey 1978

Table 49. HYBRID POPLAR (*Populus* spp.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem bark	19.14	Wisconsin	Lower stem; average value of 4 clones black poplar parentage; 4-year-old tree	Strong 1980
	19.28	Wisconsin	Lower stem; average value of 4 clones balsam poplar parentage; 4-year-old tree	Strong 1980
	19.57	Wisconsin	Upper stem; average value of 4 clones black poplar parentage; 4-year-old tree	Strong 1980
	19.31	Wisconsin	*Populus tristis* x *P. balsamifera*; 10-year-old tree	Zavitkovski 1979
	20.20	Wisconsin	Upper stem; average value of 4 clones balsam poplar parentage; 4-year-old tree	Strong 1980
Stem; composite wood and bark	19.54	Ontario	Average value for 10 clones 2-year-old trees; in general, clones with cottonwood parentage had higher calorific value than clones with aspen parentage	Sastry and Anderson 1980
	19.51	Pennsylvania	Average value for 7 clones 4-year-old tree	bowersox et al. 1979

Table 49. HYBRID POPLAR (*Populus* spp.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Branch; composite wood and bark	20.01	Wisconsin	Average value of 4 clones black poplar parentage; 4-year-old tree	Strong 1980
	20.23	Wisconsin	Average of 4 clones balsam poplar parentage; 4-year-old tree	Strong 1980
	20.05	Wisconsin	*Populus tristis* x *P. balsamifera*; 10-year-old tree	Zavitkovski 1979
Foliage	18.46	Wisconsin	*Populus tristis* x *P. balsamifera*; 10-year-old tree	Zavitkovski 1979
Individual components for *Populus maximowiczii* x *P. trichocarpa*, Clone NE-388				
a) 1-year-old wood and bark	19.61	Pennsylvania	--	Bowersox et al. 1979
b) 2-year-old wood and bark	18.96	Pennsylvania	--	Bowersox et al. 1979
c) 3-year-old wood and bark	19.16	Pennsylvania	--	Bowersox et al. 1979
d) 4-year-old wood and bark	19.19	Pennsylvania	--	Bowersox et al. 1979

Table 49. HYBRID POPLAR (*Populus* spp.) cont'd

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Individual components for *Populus maximowiczii* x *P. trichocarpa*, Clone NE-388 (cont'd)				
e) 1- to 4-year old bark	19.47	Pennsylvania	--	Bowersox et al. 1979
f) Foliage	19.06	Pennsylvania	--	Bowersox et al. 1979
g) Roots up to 4 years old, without bark	18.43	Pennsylvania	--	Bowersox et al. 1979

3.4 Calorific Values of Foreign Trees Commonly Grown in Canada

Table 50. SCOTS PINE (*Pinus sylvestris* L.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.02	England	May be composite wood and bark	Ovington 1961
	19.79	England	May be composite wood and bark	Ovington and Heitkamp 1960
Branch	20.48	England	Living branches; presumably composite wood and bark	Ovington 1961
	20.67	England	Dead branches; presumably composite wood and bark	Ovington 1961
Branch; composite wood, bark, and foliage	20.18	England	--	Ovington and Heitkamp 1960
Foliage	21.29	England	Average for 1-, 2- and 3-year-old foliage	Ovington 1961
	20.31	England	--	Ovington and Heitkamp 1960
Cones	19.75	England	--	Ovington 1961
Roots	20.03	England	Roots greater than 0.5 cm diameter	Ovington 1961
Rootlets	14.99	England	Rootlets less than 0.5 cm diameter	Ovington 1961

Table 51. AUSTRIAN PINE (*Pinus nigra* Arnold)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.98	England	May be composite wood and bark	Ovington and Heitkamp 1960
Branch; composite wood, bark, and foliage	20.65	England	--	Ovington and Heitkamp 1960
Foliage	20.62	England	--	Ovington and Heitkamp 1960

Table 52. EUROPEAN LARCH (*Larix decidua* Mill.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.21	England	May be composite wood and bark	Ovington and Heitkamp 1960
Branch; composite wood, bark, and foliage	20.77	England	--	Ovington and Heitkamp 1960
Foliage	19.29	Pennsylvania	--	Hough 1969
	20.55	England	--	Ovington and Heitkamp 1960

Table 53. JAPANESE LARCH (*Larix leptolepis* [Sieb. & Zucc.] Gord.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	20.11	England	May be composite wood and bark	Ovington and Heitkamp 1960
Branch; composite wood, bark, and foliage	21.03	England	--	Ovington and Heitkamp 1960
Foliage	20.84	England	--	Ovington and Heitkamp 1960

Table 54. NORWAY SPRUCE (*Picea abies* [L.] Karst.)

Component	Calorific value, MJ/kg	Specimen origin	Remarks	Reference
Stem wood	19.79	England	May be composite wood and bark	Ovington and Heitkamp 1960
Branch; composite wood, bark, and foliage	20.49	England	--	Ovington and Heitkamp 1960
Foliage	20.05	England	--	Ovington and Heitkamp 1960

4. DISCUSSION

The calorific data list for Canadian tree species can be characterized as follows:

(1) Of the 117 species listed in Native Trees of Canada (Hosie 1969), experimentally determined calorific data are presented for 48 trees, primarily those of commercial importance. The majority of the information was obtained from U.S. sources.

(2) Stem wood calorific values are not available for many of the commercial tree species. Branch calorific values have been commonly determined from composite mixtures of wood and bark.

(3) In general, the calorific data lists for red pine, tamarack, red spruce, eastern hemlock, red alder, and beech are incomplete.

(4) For trees native to Canada, the overall mean calorific value is 21.15 MJ/kg for softwood materials (n = 121) and 19.35 MJ/kg for hardwoods (n = 237). These averages include the data which are expressed on an ash-free or air-dry basis.

(5) The variation between reported values for a component of a particular species is generally less than 5 percent. In some cases however, the variation exceeds 10 percent.

5. RECOMMENDATIONS

It is recommended that further research be conducted to develop a complete energy checklist for Canadian tree species. It is suggested that the work be conducted in separate phases, described as follows:

Phase 1. Complete Existing Species Checklist

The work would involve conducting experimental research to fill in the missing heating values in the current checklist (due to their small sizes, it can be assumed that no further research would be required for the "shrub" species listed). Ideally, calorific values should be determined to have complete data for the following components of the commercial species outlined in the tables:

(a) Stem wood

(b) Stem bark

(c) Branch wood

(d) Branch bark

(e) Foliage

It is estimated that the experimental work (preparation, grinding, drying, testing) would cost about $30,000 for the commercial species if separate branch wood and branch bark calorific values were desired. If the tabulated composite wood and bark branch calorific values are considered suitable, the cost of conducting research to fill in the remaining items would be approximately $20,000. It is approximated that Phase 2 could be conducted in 2 months, exluding collection of the tree samples.

Phase 2. Expand Upon Existing Species Checklist

It is recommended that calorific values be experimentally determined for the following important commercial or potential biomass tree species, for which no reliable data are currently available:

Sitka Spruce (*Picea sitchensis* [Bong.] Carr.)

Mountain Hemlock (*Tsuga mertensiana* [Bong.] Carr.)

Alpine Fir (*Abies lasiocarpa* [Hook.] Nutt.)

Amabilis Fir (*Abies amabilis* [Dougl.] Forbes)

Eastern White Cedar (*Thuja occidentalis* L.)

Yellow Cypress (*Chamaecyparis nootkatensis* [D. Don] Spach)

Eastern Red Cedar (*Juniperus virginiana* L.)

Largetooth Aspen (*Populus grandidentata* Michx.)

Balsam Poplar (*Populus balsamifera* L.)

Black Cottonwood (*Populus trichocarpa* Torr. & Gray)

Hop-Hornbeam (*Ostrya virginiana* [Mill.] K. Koch)

Blue-Beech (*Carpinus caroliniana* Walt.)

Alaska Birch (*Betula neoalaskana* Sarg.)

Water Birch (*Betula occidentalis* Hook. [*Betula fontinalis*] Sarg.)

Grey birch (*Betula populifolia* Marsh.)

Sitka Alder (*Alnus sinuata* [Reg.] Rydb.)

Rock Elm (*Ulmus thomasii* Sarg.)

Choke Cherry (*Prunus virginiana* L.)

Pin Cherry (*Prunus pensylvanica* L.f.)

Black Maple (*Acer nigrum* Michx.f.)

Douglas Maple (*Acer glabrum* Torr. var. *douglasii* [Hook.] Dipp.)

Basswood (*Tilia americana* L.)

Dogwood (*Cornus* spp.)

Black Ash (*Fraxinus nigra* Marsh.)

It is estimated that Phase 2 would cost about $30,000 and could be completed within 2 months, not including material collection.

Phase 3. Determination of Factors Affecting Calorific Values

As shown in the tables, there can be considerable variation between the results of different researchers. This variation may be due to differences in tree age, geographic location, site, or experimental testing procedure. It is recommended that further research be conducted to determine the possible sources of variation and to establish accuracy levels which can be used with published calorific values. It is estimated that the cost of accurately examining 2 different species of varying ages from different sites and geographic locations would be about $40,000 and could be conducted within 4 months, excluding collection of materials.

Phase 4. Determination of Ultimate Elemental Composition of Canadian Tree Species

In addition to calorific value, the ultimate elemental composition (carbon, hydrogen, nitrogen, oxygen, and ash) of a material is often needed for energy calculations and estimations. Currently, very little information on the elemental composition of Canadian tree species is available. It is recommended that if materials are collected for Phases 1 and 2, sufficient samples be stored for ultimate elemental analysis. It is estimated that the cost of experimentally determining the elemental contents of the Phase 1 and 2 species is $35,000. This work could be conducted within 3 months.

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